Pertanika J. Sci. & Technol. 4(1): 101-113 (1996)

ISSN:0128-7680

Managing Surged Furrow Irrigation

T.S. Lee[1] and J. Tajomavwo[2]

[1]*Department of Field Engineering*
Faculty of Engineering
Universiti Pertanian Malaysia
43400 Serdang, Selangor, Malaysia

[2]*National Water Resources Institute*
Mando Road, P.M.B. 2309 Kaduna, Nigeria

Received 26 October 1994

ABSTRAK

Kelakuan proses penyusupan dalam suatu sistem pengairan merupakan ciri terpenting yang perlu ditentukan. Pengetahuan mengenai penyusupan tanah, yang mananya adalah satu proses fizikal perusa di dalam pengairan permukaan tanah, adalah penting demi untuk pelaksanaan projek pengairan. Ini ternyata dalam sistem pengairan permukaan tanah, istimewanya dengan sistem pengairan furrow. Kertas kerja ini menghuraikan kelakuan penyusupan sesuatu sistem pengairan furrow berkuatkuasa regim aliran pusuan. Kelakuan penyusupan aliran-aliran pusuan dikajikan. Cadangan-cadangan untuk implementasi pengairan praktik berorientasi pengurusan dibincang. Kaedah menilaikan ciri-ciri penyusupan pada aliran-aliran dihuraikan.

ABSTRACT

The behaviour of the infiltration process in an irrigation system is the most important feature that must be determined. Knowledge of soil infiltration, as it is a dominant physical process in surface irrigation, is crucial to the successful implementation of the scheme. This cannot be over-emphasized in surface systems, especially in furrow systems. This paper describes the infiltration behaviour of a furrow irrigation system under the surge flow regime. Infiltration behaviour over the various runs was studied. Suggestions for the implementation of such a management-oriented irrigation practice are discussed. The infiltration characteristics over the various flows are given.

Keywords: furrow infiltration, surged flow

INTRODUCTION

Conventional furrow irrigation consists of discharges into an initial set of adjacent furrows, allowing the application of water until the required depth of irrigation at the end of the furrows has been achieved. This continuous mode of operation results in tremendous loss of water not only through surface runoff, but also through deep percolation, whilst giving poor application uniformity across the field. Traditional furrow systems give poor performance with typical values of 50% water application efficiency (Walker 1984).

Prior to the emergence of this new management-oriented concept of furrow irrigation, irrigators in the United States had noticed that it was virtually impossible to irrigate long furrow fields because complete flow advance, particularly following a major cultivation, was not possible due to high intake rates (Stringham and Keller 1979). However, by diverting flows to another set of furrows after advance in the initial set of furrows seemed to have stopped, and by returning the same discharge to this partially wetted set of furrows after some hours or a day the advance could be completed (Walker and Skogerboe 1987).

From this background came the birth of the concept of surge flow. This irrigation water management technique shows marked improvements over the continuous flow regime. With surge flow, water is applied intermittently. A series of on and off discharges into the furrows can result in more rapid advance rates of the wetting front, which in turn can lead to a decrease in water loss through deep percolation. Thus by controlling the on-off cycle and the discharge flow rate, runoff at the downstream end of the furrow can be minimized. Surge flow can therefore result in water applications that are more uniform and efficient (Bishop *et al.* 1981). In view of the mode of operation, this system is open to automation by systems control and better water management techniques. For an efficient surged system, more studies must be made with respect to on-off time ratios, the optimum length of field for the respective time ratios and soil conditions and, most important of all, the antecedent infiltration rate.

Because of the importance of the infiltration process in surge flows as well as conventional irrigation, greater understanding of the infiltration process and characteristics is necessary. It is almost certain that infiltration rates under surged flows are considerably reduced during the initial few surges and it is this that allows greater flow advance down the furrows. Several research studies indicate the benefits of surge flow from the reduction in soil infiltration rates (Bishop *et al.* 1981; Trout 1990).

The objective of this study was to characterize the behaviour of infiltration under surge flow to see the changes during each of the subsequent surges over the wetted and unwetted parts of the furrow so that management strategies can be adopted. This study was done on only one particular soil type, a clayey loam soil at Universiti Pertanian Malaysia upland irrigation research site.

INFILTRATION CHARACTERISTICS

The significant physical variation of infiltration in surged flow compared to the continuous flow mode is the opportunity of a drying-out time of the soil surface and then a rewetting phase for infiltration to occur. This could be described as a soil sealing action although a crust has not yet been formed (Romkens 1994). This cyclical intermittent wetting and drying process has significantly altered the infiltration rate. How it occurs is the subject of various research studies, and this knowledge is important in order to operate and manage the surge flow concept efficiently.

In spite of the relatively short history of its development, several studies have been made to examine infiltration under surge flow conditions. Podmore and Duke (1982) found that steady state infiltration rates in silty clay loam soil were half of those measured under the continuous flow regime, while Testezlaf *et al.* (1987) reported a one-third reduction on these soils. Walker *et al.* (1982) deduced that infiltration rates decrease rapidly after the first surge and steady state infiltration rates are lower under intermittent wetting. The reduction is greater on sandy loamy soil than silty clay loam soils.

Coolidge *et al.* (1982) suggested that the reducing effect occurred primarily during the drying-out period. Tabago (1983) studying on loam soil and Izadi and Wallender (1985) on clay loam reported insignificant changes in infiltration under the modes of operation. Izuno *et al.* (1985) concluded that on silty clay loam soil steady state rates were the same irrespective of the irrigation *modus operandi*. Testezlaf *et al.* (1987) reported that under surge treatment, the infiltration rates of th
e soils rebounded upwards at the beginning of the new surge cycle and rapidly declined thereafter.

From these studies, it is noted that a more definite determination of the infiltration behaviour has to be made under surge flow. In view of the vast range of results for different soil types, it is best to perform *in situ* tests.

METHODOLOGY AND RESULTS

The site of the trials was UPM irrigation research area. The soil was of the clayey loam type with freshly prepared non-wheeled furrows of 56 m length with about 0.8% slope. The furrow spacing was 0.76 m. The surge flow regimes were accomplished through a series of individual volumes of water introduced intermittently. Three to five surge treatments with cycle ratios of 20, 30, 35, 40, 45, 60 and 80 min were used. These on-off times gave cycle ratios ranging from 0.5 to 0.75. Inflow rates used were 0.83-3.18 l/sec. Data collected included discharge, time and distance of flow advance, outflow hydrograph and furrow cross-section. At the end of each surge, for each test, if the advance had not been completed, a Parshall flume was installed at the front of the last advanced distance and the flow hydrograph was recorded for all subsequent surges. The results of the experiments are shown in Tables 1, 2 and 3 and in *Fig 1-5.* A surge by surge simple analysis is given for furrow number 10.

First Surge

This surge is similar to the continuous flow on a dry furrow. The infiltration can be derived using Kostiakov equation (Walker and Skogerboe 1987; Lee and Abdul Aziz 1993). However, it can also be determined by using the volume balanced inflow outflow method (Lee and Abdul Aziz 1993) even if the surge did not complete furrow advance. The average infiltration over the wetted segment is 1250 l over an area of 0.76 m × 44.5 m, giving an average 37 mm infiltration. A Parshall flume was installed at the end of the advance. By using the method suggested (Walker and Skogerboe 1987) the Kostiakov equation for this surge was found and is tabulated in Table 2, where Z is the infiltration depth in metres and T is the opportunity time in minutes.

Second Surge

The 1250 l of flow run over a previously wetted furrow segment and the rate of advance is faster now (*Fig. 1 and 2*). Upon meeting with the dry segment the flow rate slows down. An outflow hydrograph was taken of the outflow from the wetted segment, and this volume becomes the inflow volume for the dry segment at the front. The volume is about 500 l (*Fig. 3*), thus giving an infiltrated volume of 750 l for the first wetted segment. The average infiltration is therefore 22 mm while it was 7 mm for the dry segment. The total runoff from the end of the furrow was 438 l (*Fig. 3*).

Third Surge

Another surge volume of 1250 l now advances over the first wetted segment giving an outflow of 700 l. This gives an average infiltration of 16 mm. The average infiltration from this inflow volume and a total of 615 l runoff resulted in an average infiltration of 10 mm for the second wetted segment.

Fourth and Fifth Surges

The next two volumes of water at 1.042 l/sec inflow resulted in a steady state outflow of 0.53 l and 0.62 l respectively (Table 1), giving an average infiltration of about 15 mm.

However, since the amount of steady state outflow is virtually constant (Table 1), the simpler inflow-outflow method can be used and results are similar. With this method, the infiltration rate can be calculated to be 0.6 mm/min.

TABLE 1
Furrow field trials data

Furrow number	Inflow (1/sec)	On time/ total time cycle ratio (min)	Number of surges for advance completion	Steady state outflow (l/sec)					Remarks
				Surge number					
				1	2	3	4	5	
1	2.080	30/45	3	0	0.21	–	–	–	Advance incomplete. Ourflow into 2nd segment.
2	2.510	20/40	3	–	–	–	–	–	Advance complete. No Parshall flume record at end of 1st surge.
3	3.180	40/40	1	–	–	–	–	–	Advance complete. Like continuous flow. No outflow record.
4	2.050	15/30	2	0	0.50	0.60	0.90	0.90	Advance complete.
5	1.563	20/35	1	0.60	0.71	0.71	–	–	Advance complete.
6	1.780	10/20	1	0.40	1.00	1.00	1.00	1.00	Advance complete.
7	1.470	10/20	1	0.20	0.78	0.78	0.79	0.80	Advance complete.
8	0.830	8/20	2	0.21	0.22	0.23	0.24	0.24	Advance complete.
9	2.080	40/60	2	0	0.09	0.13	0.24	0.24	Advance complete.
10	1.042	20/30	2	0	0.53	0.62	0.62	0.62	Advance complete.

TABLE 2
Infiltration equations for furrow 10

Surge Number	Infiltration Equation
1	$Z = 0.0233T^{0.11} + 0.000623T$
2	$Z = 0.00208T^{0.219} + 0.000623T$
3	$Z = 0.00059T^{0.503} + 0.000623T$
4	$Z = 0.000274T^{0.789} + 0.000623T$
5	$Z = 0.000274T^{0.789} + 0.000623T$

TABLE 3
Infiltration rate of the various surge runs for furrow 10

Surge number 1

Distance Advance (m)	Flow Advance Time (min)	Infiltration Opportunity Time (min)	Accumulative Infiltration (mm)	Infiltration Rate (mm/min)
0	0.000	20.000	44.854	2.243
5	0.583	19.417	44.386	2.286
10	2.267	17.733	43.016	2.426
15	6.350	13.650	39.565	2.899
20	8.450	11.550	37.691	3.263
25	12.580	7.420	33.670	4.538
30	16.500	3.500	28.923	8.264
35	17.000	3.000	28.162	9.387
44.5	20.000	0.000	0.000	

Surge number 2

Distance Advance (m)	Flow Advance Time (min)	Infiltration Opportunity Time (min)	Accumulative Infiltration (mm)	Infiltration Rate (mm/min)
0	0.000	20.000	16.469	0.823
5	0.380	19.620	16.215	0.826
10	1.150	18.850	15.700	0.833
15	1.467	18.533	15.488	0.836
20	1.933	18.067	15.176	0.840
25	2.450	17.550	14.829	0.845
30	3.217	16.783	14.313	0.853
35	4.010	15.990	13.779	0.862
40	4.714	15.286	13.303	0.870
45	5.433	14.567	12.815	0.880
50	6.580	13.420	12.034	0.897
55	7.830	12.170	11.177	0.918
56	7.860	12.140	11.157	0.919
				Average = 0.862

Surge number 3

Distance Advance (m)	Flow Advance Time (min)	Infiltration Opportunity Time (min)	Accumulative Infiltration (mm)	Infiltration Rate (mm/min)
0	0.000	20.000	15.122	0.756
5	2.267	19.733	14.938	0.757
10	0.633	19.367	14.685	0.758
15	0.983	19.017	14.443	0.759
20	1.317	18.683	14.212	0.760
25	1.733	18.267	13.924	0.762
30	2.300	17.700	13.520	0.764
35	2.850	17.150	13.149	0.767
40	3.480	16.520	12.710	0.769
45	3.767	16.233	12.510	0.770
50	4.467	15.533	12.021	0.774
55	4.867	15.133	11.742	0.776
56	4.930	15.070	11.718	0.777
				Average = 0.765

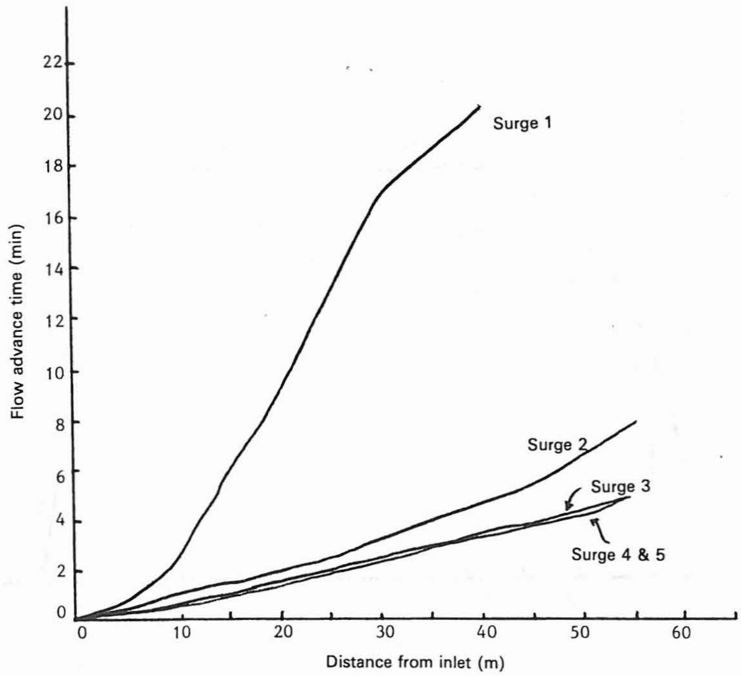

Fig. 1. Surge flow advance curves for furrow 10

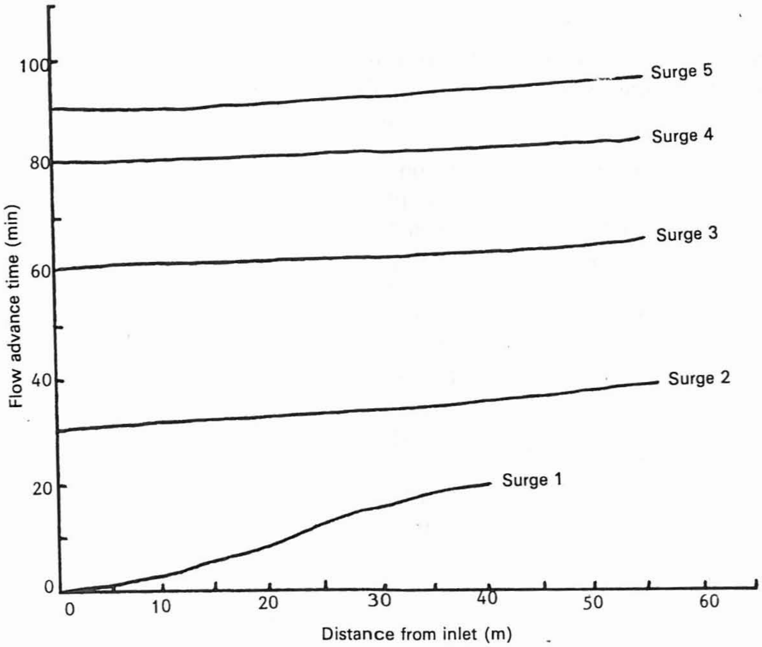

Fig. 2. Comparison of surge flow advance rates for furrow 10

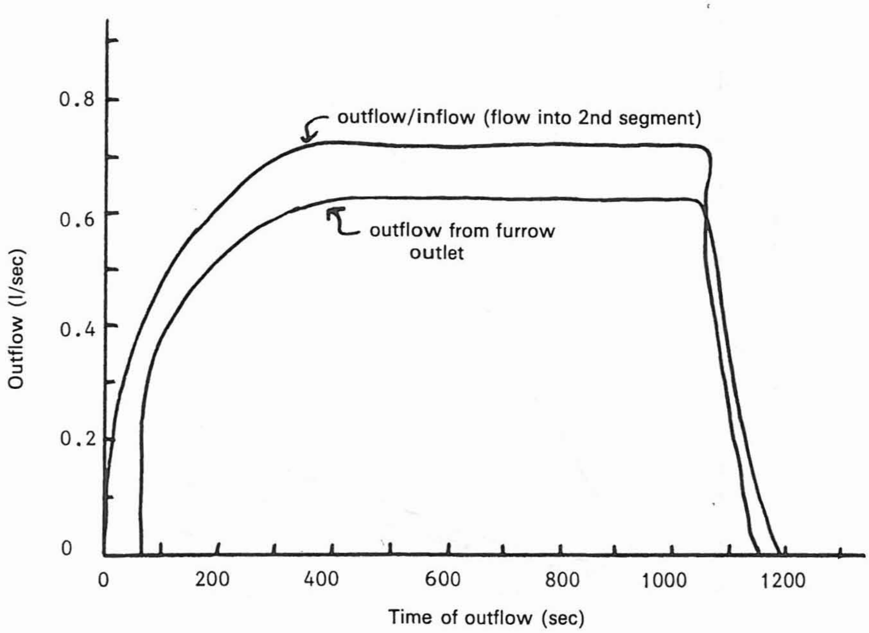

Fig. 3. Outflow hydrograph for Parshall flumes for surge 2 of furrow 10

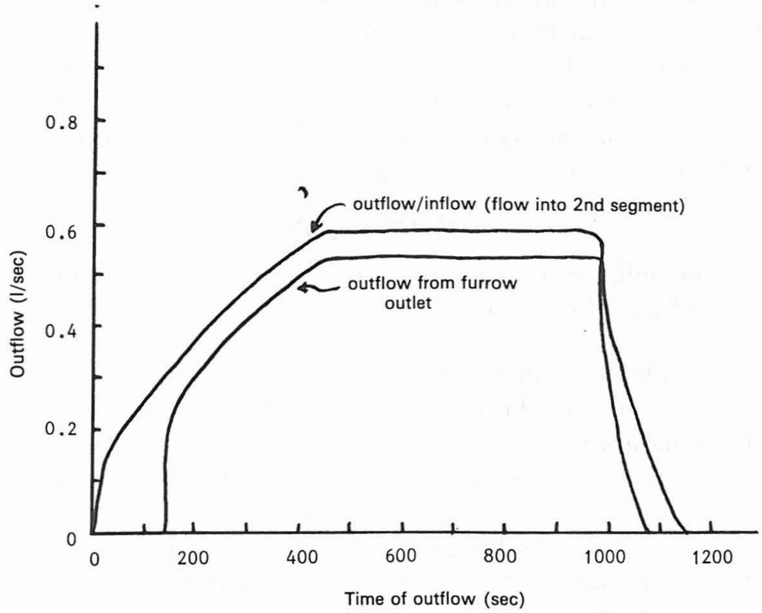

Fig. 4. Outflow hydrograph for Parshall flumes for surge 3, 4 and 5 of furrow 10

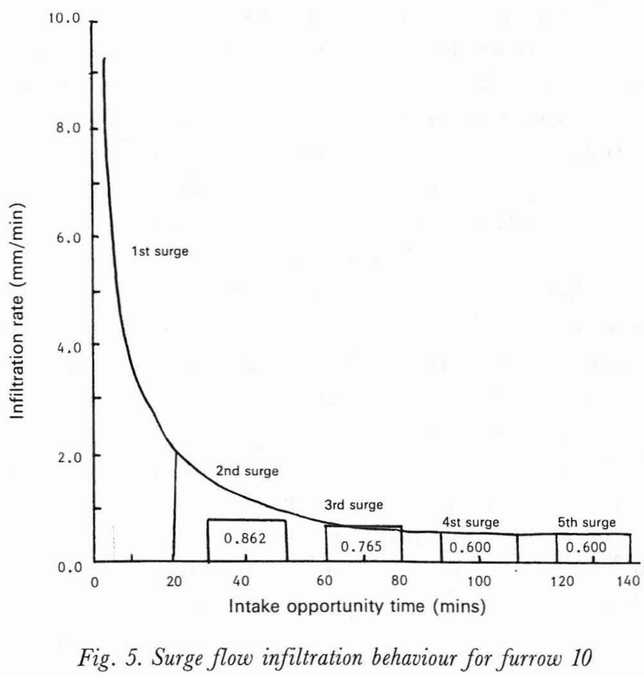

Fig. 5. Surge flow infiltration behaviour for furrow 10

It can be seen that upon completion of advance by the second surge, the soil has reached a fairly uniform infiltration rate along the whole furrow (Tajomavwo 1992). This is obviously supported by the fact that advance curves (*Fig. 1*) and advance rates (*Fig. 2*) are similar. *Fig. 5* shows the rapid decay of infiltration rate typical in a surge flow. The obvious reason for this is the surface sealing effect of surging.

DISCUSSION

In surge flow, infiltration behaviour depends on the flow nature. This can be said to fall into three categories:

a) a distinct flow advance over a dry furrow
b) flow advance over the previously wetted part and a dry part at the advancing front
c) flow advance over a completely wetted whole length of furrow.

Depending on the discharge into furrows, in longer furrows the flow nature follows the pattern described above. In shorter furrows (definition of short furrows in this text is resticted to that in which with the given discharge, flow advanceis complete with the first surge) the flow would follow that of part (a) and (c) only. From a management point of view, if the same discharge is maintained in short furrows after completion of advance. Thus it is important to operate the system with reduced inlet discharge. The question would then be how much the discharge reduction should be.

From the description of the nature of flows, it can be seen that there are two or three types of infiltration action, depending on the length of the furrow. In the completely dry phase, the infiltration function can be estimated by using the Kostiakov equation. In the completely wetted phase, it is safe to estimate the infiltration function by using the final basic infiltration rate (here determined by using the inflow outflow method for the first surge completing advance and the corresponding outflow hydrograph) because the rate of flow advancing over the wetted phase seems extremely constant over the surges. This indicates that the infiltration rate over the length of furrow is quite constant.

The difficult part is to deal with the intermittent dry/wet phase where the flow over a wet plane merges into the dry plane. Information on the infiltration function over this phase has to be deduced. From a practical point of view (until such information is available), it is not possible to determine where the dry/wet interphase would be at for any irrigation event. To record information of the infiltration at points along the furrow would be rather impractical for the irrigator, let alone keeping track of information on the numerous furrows. Thus from a practical management viewpoint, the following strategy should be adopted:

a) depending on the length of furrow (and soil type), use a sufficiently large discharge and ensure complete advance either with a little runoff or time the discharge cut-off time such that at cut-off time, the volume of water is sufficient to ensure the rest of the furrow can be wetted.

b) upon completion of the above phase, let the furrow rest to ensure that no water remains. This should be quite fast with lighter soils or coarser soils. In heavier soils, runoff would also ensure this phase is quite fast.

c) next, re-introduce a cut-back discharge into the wetted furrow. The amount of cut-back would be dependent on the final basic infiltration rate. From a practical point of view, there are two ways to operate this. First, a cut-back discharge operated over a set on-time. Second, a cut-back in discharge-on-time (while maintaining the same discharge). The ultimate aim is to ensure that minimal runoff occurs at the end of the furrow. To achieve this, there would have to be a drastic reduction in the discharge-on-time allowed for the same capacity discharge. This is the better option in terms of operational procedure than to reduce the valve openings required in cut-back discharge. It has been observed (Lee 1982) that for heavier soil types, reducing on-time to as much as one-third of the original on-time is sufficient to ensure flow advance, by that reduced surge, is complete in the wetted furrow.

These steps would ensure more infiltration uniformity along the furrows and also across the furrows. This is primarily the objective of an irrigation event.

On the aspect of cycle ratio, it is noted that for similar discharges in furrows 5, 6 and 7 (with cycle ratios of 0.57, 0.5 and 0.5 respectively) the rates of advance over the furrows with completed advance are very similar. This was shown true for furrows 4 and 8 which had similar discharges but different cycle ratios of 0.5 and 0.4. From the experiments it was noted that for completely dry advance, the discharge volume (the discharge rate multiplied by the on-time) would have a tremendous effect on the time (and number of surges) to complete advance. However, the cycle ratio does not affect the rate of advance over furrows with completed advance because upon completion of advance, the infiltration rate over the wetted furrow has become more uniform.

Furrow length is an important aspect in the implementation of surge flow operations because for similar discharge and soil conditions, the length may be crucial in determining whether advance can be completed and in cases where advance has been completed, whether runoff is minimal or otherwise. Longer furrows (> 400 m) in lighter soils require large inlet discharges to ensure complete surge advances. Shorter furrows, such as those in this study (50 m) allow substantial runoff to be wasted. From personal experience (Lee 1982), for the kind of typical discharges mentioned above, 200-m long furrows are suggested for silty clay loam, clayey loamy, loamy and sandy loam soils, with the discharge size increasing for lighter soils. However, cut-back irrigation must be implemented, especially in the heavier soils and slopes suitable for furrow irrigation.

CONCLUSION

From the study of surge flow on clayey loam soil at Universiti Pertanian Malaysia research site, the following conclusions can be drawn.

1. Infiltration over the various surges in a particular furrow can be determined simply by an inflow/outflow method. Upon completion of advance, the infiltration rate over the whole furrow length is uniform.
2. Size of discharge volume is important for determining the completion of advance. Discharge rate and the cycle ratio term may not be important upon completion of advance because of the uniform infiltration rate achieved.
3. In most soils, cutback in discharge on-time (to reduce the total volume input) is important to avoid serious runoff wastage.
4. For surge furrow irrigation, the suggested length of the field (with cutback irrigation) should be about 200 m for the 0.5-2.0 l/sec flow rates common in this type of irrigation.
5. In furrow irrigation there are two major problems. The first is that flow advance should be complete in all furrows to achieve irrigation uniformity. The second is the minimization of deep percolation and runoff. The first can be solved by fast surging to ensure quick and complete advance. In the second problem, deep percolation is reduced by the surging effect itself, whereas end runoff can be overcome by cutback discharge on-time and possibly in conjuction with the use of blocked furrows.

REFERENCES

BISHOP, A.A, W.R. WALKER, N.L. ALLEN and G.J. POOLE. 1981. Furrow advance rates under surge flow systems. *Journal of Irrigation and Drainage Division, ASCE* **107(IR3)**: 257- 264.

COOLIDGE, P.S., W.R. WALKER and A.A. BISHOP. 1982. Advance and runoff - surge flow irrigation. *Journal of Irrigation and Drainage Division, ASCE* **108 (IR1)**: 35-42.

IZADI, B. and W.W. WALLENDER. 1985. Furrow hydraulic characteristics and infiltration. *Transactions of ASAE* **28(6)**: 1901-1908.

IZUNO, F.T., T.H. PODMORE and H.R. DUKE. 1985. Infiltration under surge irrigation. *Transactions of ASAE* **28(2)**: 517-521.

LEE, T.S. 1982. Personal involvement in surge flow field trials carried out at Utah State University, Logan Utah; Kimberly, Idaho; and Flowell, Utah, USA.

LEE, T.S. and ABDUL AZIZ ZAKARIA, 1993. Measuring infiltration characteristics in furrow irrigation. In *National Conference on Engineering Education and Research*. Universiti Pertanian Malaysia, 15-16th June 1993.

PODMORE, T.H. and H.R. DUKE. 1982. Field evaluation of surge irrigation. ASAE Paper No. 82-2102. St. Joseph, MI.

ROMKENS, M. 1994. Soil surface sealing - theory development and failure. Seminar paper, Faculty of Agriculture, Universiti Pertanian Malaysia, 1st June 1994.

STRINGHAM, G.E. and J. KELLER. 1979. Surge flow for automatic irrigation. In *Proceedings, 1979 Irrigation and Drainage Division Specialty Conference, ASCE*. Albuqueque, New Mexico, July 1979.

TABAGO, J.L. 1983. Adaptation and evaluation of surge irrigation under Phillipine conditions. Ph.D. dissertation, Oklahoma State University.

TAJOMAVWO, J. 1992. Infiltration characteristics under surge flow irrigation. Master of Science in Irrigation dissertation, University of Newcastle upon Tyne - Universiti Pertanian Malaysia.

TESTEZLAF, R., R.L. ELLIOTT and J.E. GARTON. 1987. Furrow infiltration under surge flow irrigation. *Transactions of ASAE* **30(1)**: 193-197.

TROUT, T.J. 1990. Surface seal influence on surge flow furrow infiltration. *Transactions of ASAE* **34(1)**: 66-72.

WALKER, W.R. 1984. Optimizing surface irrigation performance. *In Water: Today and Tomorrow*, ed. J.A. Replogle and K.G. Renard. American Society of Civil Engineers.

WALKER, W.R. and G.V. SKOGERBOE. 1987. *Surface Irrigation: Theory and Practice*. Englewood Cliffs: Prentice-Hall.

WALKER, W.R., H. MALANO and J.A. REPLOGLE. 1982. Reduction in infiltration rates due to intermittent wetting. American Society of Agricultural Engineers Paper No. 82 - 2029, St. Joseph, MI.